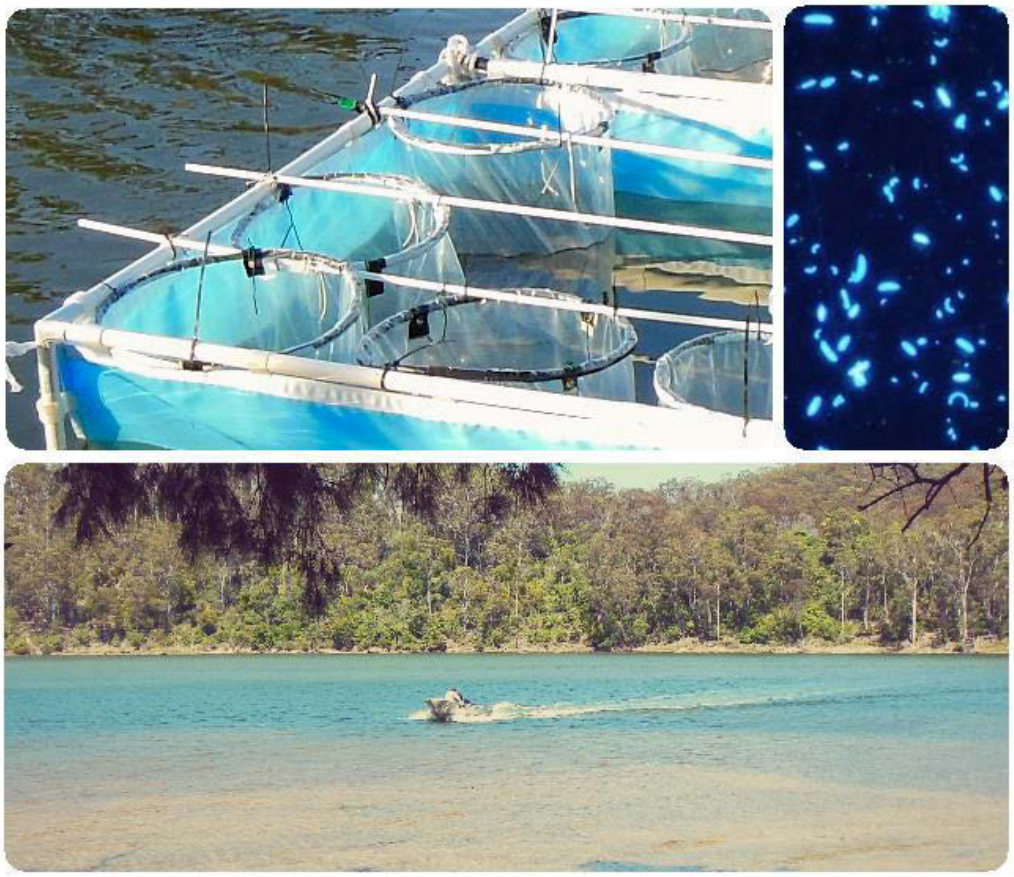
Freshwater inflows to estuaries: Organic carbon and microbial food webs in south-east Australia



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A thesis in fulfilment of the requirements
for the degree of Doctor of Philosophy

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Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text. I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature Date

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Preface

This thesis consists of seven chapters. Chapters two to six are self-contained and written as journal articles and have either been published, are under revision or soon to be submitted. I have presented them here similar to their published or submitted form and as a result some repetition occurs. These papers are presented in a logical theoretical order. Where these papers cross reference each other I have included chapter numbers. To prevent unnecessary duplication, a single reference list is provided at the end of the thesis. In addition because Chapters two to six are co-authored papers there is a shift from singular, I, to the plural we, within the text.

This thesis is a compilation of my own work with guidance from my supervisor and others. I conceptualized my research, conducted all data collection and analysis, and wrote the manuscripts. My supervisors and co-authors proof-read and edited the final manuscript versions. Publication details and Contributions of co-authors are detailed below:

Chapter 2: Hitchcock, J. N and Mitrovic, S. M. 2014. Highs and Lows: the effect of differently sized freshwater inflows on estuarine carbon, nitrogen, phosphorus, bacteria and chlorophyll *a* dynamics. *Estuarine, Coastal and Shelf Science*. In press, doi:10.1016/j.ecss.2014.12.002

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

Chapter 3: Hitchcock J. N. and Mitrovic, S. M. 2015. After the flood: Changing dissolved organic carbon bioavailability and bacterial growth following inflows to estuaries. *Biogeochemistry*. In press, doi:10.1007/s10533-015-0094-3

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

Chapter 4: Hitchcock, J.N. & Mitrovic, S.M. 2013, 'Different resource limitation by carbon, nitrogen and phosphorus between base flow and high flow conditions for estuarine bacteria and phytoplankton', *Estuarine, Coastal and Shelf Science*, vol. 135, pp. 106-15.

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

Chapter 5: Hitchcock, J. N., Mitrovic, S. M., Hadwen, W. L., Growns, I. O. and Rohlfs, A. 2014. Zooplankton responses to freshwater inflows and organic matter pulses in a wave-dominated estuary. *Marine and Freshwater Research*. In prep.

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

W. L. Hadwen provided conceptual advice, guidance and sample analysis relating to stable isotopes.

I. O. Growns provided conceptual advice and guidance.

A. Rohlfs provided field assistance.

Chapter 6: Hitchcock, J. N., Mitrovic, S. M., Hadwen, W. L., Roelke, D. L, Growns, I. O. and Rohlfs, A. 2014. Chapter 6 Terrestrial dissolved organic carbon subsidises estuarine zooplankton: an *in-situ* mesocosm study. *Limnology and Oceanography*, In prep.

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

W. L. Hadwen provided conceptual advice, guidance and sample analysis relating to stable isotopes.

D. L. Roelke provided conceptual advice, guidance and field assistance.

I. O. Growns provided conceptual advice and guidance.

A. Rohlfs provided field assistance.

Other papers published during my candidature but not forming part of this thesis:

Mitrovic, S.M., Westhorpe, D.P., Kobayashi, T., Baldwin, D.S., Ryan, D., Hitchcock, J.N., 2014. Short term changes in zooplankton density and community structure in response to different sources of dissolved organic carbon in an unconstrained lowland river: evidence for food web support. Journal of Plankton Research, vol. 36, pp 1488-1500

Contents

List of Figures

List of Tables

List of Abbreviations

BB	Bacterial biomass
BDOC	Bioavailable dissolved organic carbon
BGE	Bacterial growth efficiency
BGR	Bacterial growth rate
C	Carbon
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
DON	Dissolved organic nitrogen
DNP	Dissolved non-reactive phosphorus
FWI	Freshwater inflows
LTB%	Long-term percent carbon bioavailability
LTC	Long-term bioavailable dissolved organic carbon
N	Nitrogen
P	Phosphorus
POC	Particulate organic carbon
Q	Mean daily discharge
$Q10$	Mean 10 day antecedent discharge
STB%	Short-term percent carbon bioavailability
STC	Short term bioavailable dissolved organic carbon
SUVA	Specific ultra-violet light absorption
TN	Total nitrogen
TP	Total phosphorus
WSP	Water sharing plan

Abstract

Freshwater inflows (FWI) play a crucial role in maintaining estuarine processes and productivity. River regulation and extraction have greatly reduced FWI to estuaries. Little attention has been paid to the role FWI has in delivering organic carbon to estuaries. The aim of this thesis was to define the relationship between freshwater inflows, organic carbon, bacteria and zooplankton dynamics. To do this, I performed a series of monitoring and experimental studies on the Bega and Clyde River estuaries, Australia.

Discharge on both rivers was highly episodic during the study. On the Bega and Clyde Rivers, increasing dissolved organic carbon (DOC) concentrations were closely coupled with increasing discharge. The bioavailability of DOC increased during FWI events, and in turn bacterial growth rates were also higher during and immediately following inflow events. Bacterial growth was carbon limited most of the time, though during high flows, bacteria often became phosphorus limited. Changing availability of DOC and phosphorus during inflow events was the main reason for shifting resource limitation. On both rivers bacterial biomass was positively related to increasing DOC and phosphorus concentrations. Highly episodic discharge during this study had a major structuring role over carbon and bacteria dynamics.

On the Bega River I found strong evidence that allochthonous carbon and bacteria can subsidise zooplankton production following the input of DOC during FWI events. Zooplankton density increased following a flooding event on the Bega River and stable isotope analysis indicated allochthonous terrestrial carbon was the dominant source of carbon utilised by zooplankton. Experimental mesocosms confirmed that allochthonous carbon and bacteria can support increased zooplankton in the presence of high subsidies.

The individual studies forming this thesis all contribute new insights to their respective sub-disciplines within aquatic ecology. Viewed together, they present a novel conceptualisation of hydrology and freshwater inflows in the coastal carbon cycle and microbial food webs in south-east Australian estuaries. The results provide a strong case to protect freshwater inflows to estuaries.